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Comparing Text and Graphics in Navigation Display Design

Kevin W. Williams
FAA Civil Aeromedical Institute
Oklahoma City, OK 73125

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16. Abstract

Thirty-six pilots were tested in a flight simulator on their ability to decide which of two airports was farther from a storm front, based on the manner in which information was presented on a navigational display. The results support the superiority of graphical over textual information display of nearest airport information. Pilots were significantly faster using the map display than using either the text-only display or the enhanced-text display. In addition, in contrast to an earlier study (Williams, 1999), pilots performed better using a north-up map than when using a track-up map. Discussion of the results focuses on recommendations for moving-map displays and the display requirements for support of the nearest-airport function within a navigational display.

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Comparing Text and Graphics In Navigation Display Design

INTRODUCTION

Since the advent of graphics-capable computer systems there has been a question of whether graphically presented information is more effective than information presented in a textual format (DeSanctis, 1984; Tullis, 1981). The types of tasks tested have varied from data base retrieval (Boehm-Davis, Holt, Koll, Yastrop, & Peters, 1989) to military tactical decision making (Wickens & Scott, 1983). While common opinion might support the superiority of graphically presented information, it is interesting to note that not all of the empirical data show a clear advantage of graphically presented information over textually presented information. Nawrocki (1972), for example, found no significant advantage to either graphics or text when subjects were required to remember previously presented information. In addition, research examining the performance on procedural tasks as a function of whether instructions are presented verbally, graphically, or in combination has shown that pictures alone often lead to quicker completion times on procedural tasks, but words lead to greater accuracy (Booher, 1975; Rigney and Lutz, 1976; Stern, 1984).

Tullis (1981) suggested that the main conclusion to be drawn from a review of these studies is, not surprisingly, that the effects of graphics on human performance are highly dependent upon the task. It is useful, therefore, to ask what task factors influence this performance. Wickens and Scott (1983) identified two factors that might influence the effectiveness of graphically versus textually presented information. The first factor is the compatibility between the stimulus, the cognitive processing, and the response required for the task (or S-C-R compatibility). That is, if the information displayed (the stimulus) matches or corresponds to the type of processing and response required for the task, then the task will be performed more quickly and effectively than if no such compatibility exists. Wickens, Sandry, and Vidulich (1983) proposed that tasks that demand spatial/analog processes in working memory will be best served by visual spatial displays and more poorly served by textual displays.

A second factor suggested by Wickens and Scott is the degree to which several pieces of information can be presented in a simultaneous, integrated format. For example, two different pieces of information can be displayed graphically as the height and width of a rectangle. The area of the rectangle could then be perceived in an integral fashion so that both pieces of information are processed simultaneously. The relative importance of both of these factors is undecided (see Boehm-Davis et al., 1989).

The question of graphically versus textually displayed information was recently studied in the context of navigational display design (Williams, 1999). Most navigational displays found in General Aviation (GA) aircraft today are used in combination with global positioning system (GPS) units. GPS units have a function for displaying the nearest waypoints to the current position of the aircraft. The types of waypoints that can be displayed include very high frequency omnirange (VOR) facilities, nondirectional beacons (NDB), navigation intersections, and airports. The use of the nearest waypoint function for the display of nearest airport information is relevant to pilot safety considerations, since this information would likely be used under emergency and/or distress conditions.

In most current GPS units, nearest airport information is displayed in a text-based format, even if the unit contains a moving-map display. The information usually given to the pilot includes the airport identifier, bearing to the airport, and distance to the airport, for the closest 10 to 20 airports from the current aircraft position. The decision to display this information in a textual format is most likely based on programming convenience (Boehm-Davis et al., 1989).

Since many GPS units have a moving-map display, it is possible to present airport distance and bearing information directly on the moving map, rather than in a text-based tabular format. Williams (1999) asked participants to judge the relative bearing to the nearest airport. Nearest airport information was presented in either a tabular, text-based format, or directly within a moving-map display. In addition, a third

condition involved a text-based format that included an orienting symbol next to each airport identifier. For the map-based condition, the map was oriented either in a north or track-up manner.

Results from the study showed that the use of the tabular, text-only format normally found on such displays was significantly slower and less accurate than either a map display of nearest airport information or the text display that included the orientation symbol. In addition, it was found that participants were faster and more accurate with the track-up map display than with the north-up map display at indicating the relative bearing to the nearest airport. Another important finding from the study was that pilots tended to ignore information available from the heading indicator, and instead focused solely on the GPS display to perform the task.

The results indicated that the graphical display had both the advantage of S-C-R compatibility with the required task (which was essentially a visualization of the relative bearing to the airport) and an advantage due to the integration into a single presentation of current aircraft heading and bearing to the nearest airport. Furthermore, since the advantage possessed by the graphical display was eliminated when an orientation symbol was included in the text display, it seems that, at least for this task, the integration factor was more important than S-C-R compatibility. This conclusion is based on the assumption that the orientation symbol, as with the map display, integrated the current aircraft heading and bearing to the airport into a single presentation.

Several questions arose from the results of Williams (1999) that bore further study. One question was in regard to the type of task that was performed. Participants in the original study were required to make an ego-referenced judgment as to the relative direction of the nearest airport (see Williams, 1999 for details of the task). Under the text-only condition, this task required the participants to integrate information about the current aircraft heading and the absolute bearing to the nearest airport. If the task were changed from one requiring an ego-referenced judgment to one requiring a world-referenced judgment (Harwood &Wickens, 1991; Hooper & Coury, 1994; Wickens, 1992), there would be no need to integrate heading and bearing information. This could possibly eliminate the advantage demonstrated by the map-based display over the text-only display. It would also eliminate the advantage of the enhanced-text display. In addition, changing the task from one requiring an ego-referenced judgment to one requiring a world-referenced judgment would favor the use of a north-up map over a track-up map (Wickens, 1992).

A second question from the original study concerned the type of participants used in the study. The original study used both certificated pilots and non-pilots. Results from the study demonstrated that the non-pilots were significantly slower than pilots at performing the task. Eliminating non-pilots from the study might also eliminate the significant advantage of the graphic display over the text-only display.

A third question concerned the focus of attention of the pilots during interaction with the GPS display. Pilots tended to focus solely on the GPS display during the 5 to 10 seconds required to complete the orientation task. Because of the stability of the simulation, this was not a problem as far as the flight path of the aircraft was concerned. However, if the simulation were less stable, possibly through the use of a turbulence model, a 5 to 10 second lapse of attention away from the flying task could lead to much more noticeable effects on the flight path of the aircraft.

The present experiment was designed to answer these questions. The task was changed from one requiring an ego-centered judgment (deciding the relative direction to the nearest airport) to one requiring a world-centered judgment (deciding which of two airports was furthest away from an approaching storm front). As in the original experiment, three display types were tested. These types were a text-only, tabular presentation of nearest airport information, a text-based display that included an orientation symbol (called the enhanced-text display), and a graphical, map-based presentation. Refer to Figures 3-5 for depictions of these three display types.

A second variable manipulated was the map display type. The map display was shown in either a north-up or a track-up configuration. For the enhanced-text condition, the orientation symbol showing the position of each airport was relative to the current aircraft heading or relative to north. A third variable manipulated in the study was the direction of travel for the aircraft. The plane was heading either relatively north (i.e., between a heading of 345 degrees and 015 degrees, inclusive) or relatively south (i.e., between a heading of 165 degrees and 195 degrees, inclusive).

A final variable of interest was the level of turbulence present during the task. It was suspected that if pilots did not attend to the flying task while interacting with the GPS display, the presence of turbulence would not affect the amount of attention required to interact with the GPS display. On the other hand, if pilots did attend to flying while interacting with the GPS display, the presence of turbulence should increase the overall workload and lead to noticeable degradations in performance with the GPS decision task.

METHODS

Participants

Thirty-six participants were recruited from the Oklahoma City metroplex area. Thirty-three participants held current private pilot certificates, and three were currently completing flight training for a private pilot certificate. Pilots were recruited from local fixed-base operations (FBOs). All participants were paid. Information was collected regarding participants' education level, gender, flight experience, age, handedness, and GPS experience. Among the participants, only two were female. The median number of flight hours of the group was 295, ranging from 7 to 11,000 hours. Twenty of the thirty-six pilots, or approximately 56%, had experience using a GPS unit.

Facilities

Data collection was performed using the Basic General Aviation Research Simulator (BGARS) located at the FAA Civil Aeromedical Institute in Oklahoma City. BGARS is a medium-fidelity, fixed-base, computer-controlled flight simulator. The controls and displays used in the BGARS for this study simulate those of a Beech Sundowner. Control inputs are provided by high-fidelity, analog controls, including a damped and self-centering yoke, navigation radio frequency selection module, rudder pedals, throttle, gear, flap, and trim controls. Instruments are displayed on a Cathode Ray Tube (CRT) and react in real time to control inputs and aircraft conditions. The external views consist of a 50-degree forward-projected view, two smaller right-side-view CRTs, and two smaller left-side-view CRTs. A GPS display was hosted on a 10-inch, True Point™, touch-screen panel located just to the right of the pilot position and within easy reach of the pilot. Participants interacted with the panel using only their right hand. Figure 1 shows the BGARS setup with the touch-screen panel located in the lower right-hand corner of the picture.

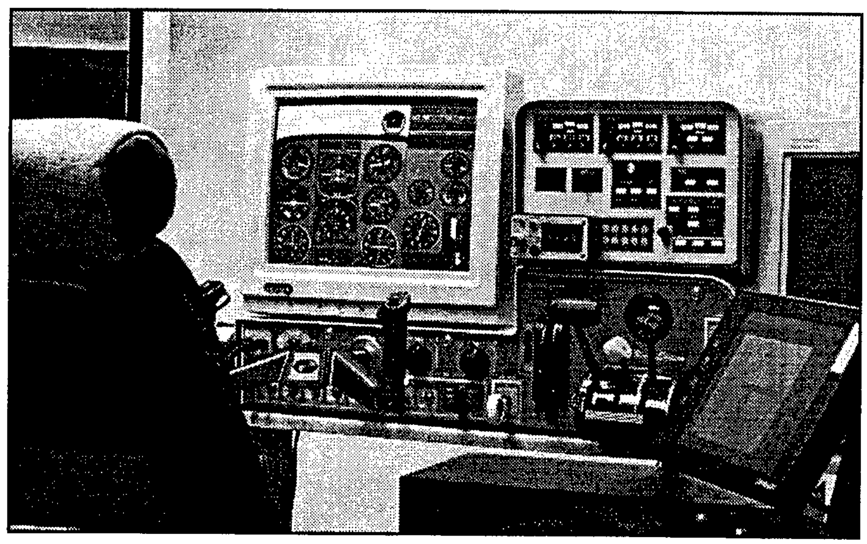
Figure 1: The Basic General Aviation Research Simulator.

Experimental Design

Four factors were manipulated in the experiment: 1) nearest airport information display mode (text-only display, enhanced-text display, map display); 2) map display mode (north-up or track-up); 3) aircraft heading (generally north or generally south); and 4) turbulence (on or off), resulting in a 3 x 2 x 2 x 2 experimental design. All conditions were manipulated within-subject. Dependent variables that were collected were decision time, decision accuracy (i.e., selecting the correct airport), and navigational accuracy (i.e., deviation from the assigned heading at the end of the trial).

Design of Trials

Four aircraft headings were used in the experimental trials. Two headings were for the generally north condition (345 degrees and 015 degrees), and the other two headings were used in the generally south condition (165 degrees and 195 degrees). In addition, four pairs of airports were selected from a navigational chart of the Oklahoma area for use in the experiment. Two of the airport pairs were located east and west of each other. The other two pairs were

located north and south of each other. Each airport was approximately 20 miles from its paired airport. No airport was located close to a large metropolitan area.

For each airport pair and for each aircraft heading, four aircraft positions were selected that met the following conditions: 1) the position was approximately halfway between both airports but at least two miles closer to one airport than the other; and 2) the direction to the closest airport corresponded to one of four clock directions relative to the aircraft, consisting of either the 1, 4, 7 or 10 o'clock positions or the 2, 5, 8 or 11 o'clock positions. Relative clock directions were defined such that 12 o'clock was directly in front of the aircraft and 6 o'clock was directly behind the aircraft, with all other clock positions relative to these. For two of the airport pairs, the clock directions were 1, 4, 7 and 10 o'clock, for the other two pairs, the clock directions were 2, 5, 8 and 11 o'clock. The total number of positions selected was 4 (airport pairs) x 4 (headings) x 4 (clock positions) = 64 positions. From these 64 positions, 48 were selected at random for each subject to be used during the experiment. The positions were selected randomly with the constraints that half were north and half were south aircraft headings, and for half of the north and south trials the relative direction of the nearest airport was in front of the aircraft (the 1, 2, 10, or 11 o'clock positions); for the other half, the relative direction of the nearest airport was behind the aircraft (the 4, 5, 7 or 8 o'clock positions).

Procedure

Participants were tested individually. Each participant received a consent form to read and sign and then completed a questionnaire. Questions determined the participant's age, gender, handedness, educational level, flight experience, and GPS experience. After completing the questionnaire, the participant was seated at the simulator, and an explanation of the experimental task was presented. During the actual experiment, presentation of trials was grouped by presentation mode (text, map, enhanced-text) within map mode (track-up, north-up). Participants received ten practice trials on a particular presentation mode and then were given four actual trials for that mode during the first half of the experiment. During the second half of the experiment, participants received two practice trials on a particular mode and then were given four actual trials for that mode. Within each set of four actual trials, the order of northbound and southbound trials was random. For two of the four tasks within each presentation mode, turbulence was added to the simulation, making the flight dynamics unstable and requiring more extensive control inputs to maintain a particular heading and altitude. In all, 36 practice trials were completed, along with 24 actual trials, making a total of 60 trials for each subject. The order that participants received presentation and map mode conditions was counterbalanced.

Following completion of the experimental task, participants were debriefed and asked which of the experimental conditions they preferred and whether or not they made use of the orientation symbol during the enhanced-text condition. Their preferences were recorded, and they were then dismissed.

Decision Task

Figure 2 shows an example of the GPS display (north-up map mode) at the beginning of each trial. Under the track-up map mode, the airplane symbol pointed straight up and the current aircraft heading was shown in the center box above the moving-map display (in place of the large "N"). Participants flying the simulator were asked to maintain the course shown on the display. In addition, they were asked to descend or climb to 3000 feet MSL, from a starting altitude of either 2500 feet or 3500 feet MSL, and then to maintain that altitude during the remainder of the trial. No airports were shown on the moving-map display until after the nearest airport function had been activated to prevent participants from beginning the judgment task early. Note that, regardless of the display condition used for the trial, pilots were shown a moving map display in either a track-up or north-up orientation prior to the judgment task. This included the text and enhanced-text conditions. The actual judgment task began when a large red "EMERGENCY" message appeared just above the airplane symbol, accompanied by a steady beeping from the computer speaker, which was the indication for the pilot to begin the task.

Pilots were asked to perform a three-step judgment procedure. The first step was to press the "NR" button on the display to bring up the nearest airport information. The second step was to note the information at the bottom of the display indicating the position of an approaching storm front. Based on this information, and the locations of the two airports, the third step was to decide which of the two airports

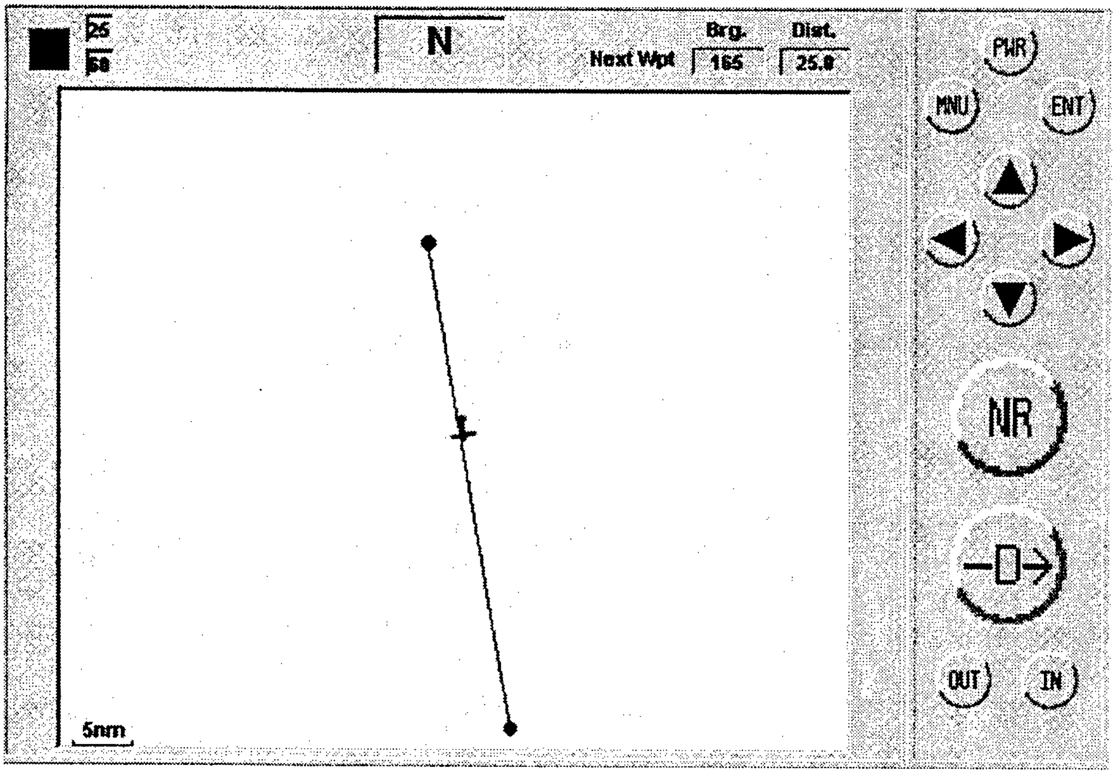

Figure 2: Example GPS display at the beginning of each trial (north-up map mode)

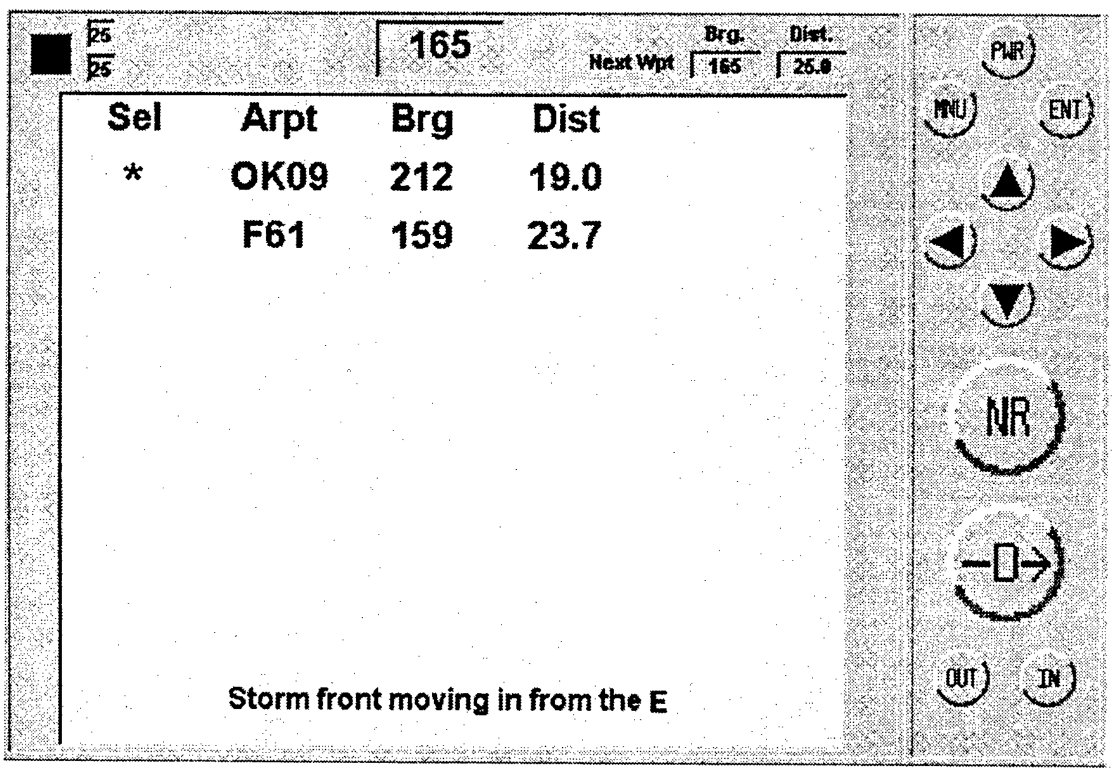

Figure 3: Text-only method of presenting nearest airport information.

was farther from the approaching storm front and to indicate this by touching the airport, or its identifier, on the touch-screen panel. For the text conditions, this meant touching anywhere along the line of text for that airport (see Figure 3 for a depiction of the airport information on the text display). For the map condition, this meant touching the airport symbol itself on the moving-map display (see Figure 5 for a depiction of the airports on the moving map display). After the pilot touched one of the two airports on the display the trial ended and the next trial was immediately begun.

Nearest airport information was presented in one of three ways. The first method, shown in Figure 3, was called the text-only method. In this method, the nearest airports were listed in a tabular format on the screen with the airport identifier, bearing to the airport, and distance to the airport shown. An asterisk was positioned next to the closest airport. In the example shown in Figure 3, the aircraft is on a heading of 165 degrees. The nearest airport, OK09, is at a bearing of 212 degrees, southwest of the aircraft. The other airport, F61, is at a bearing of 159 degrees, southeast of the aircraft. The pilot, after noting that the message at the bottom of the display indicates that the storm is approaching from the east, would touch the line of text for the airport located to the southwest, airport OK09.

The second method for presenting nearest airport information is shown in Figure 4. Known as the enhanced-text method, this method is similar to the text-only method, with the exception of an additional symbol located to the right of the airport information. This symbol is an indication of the direction to each of the airports listed. When the display was configured in a north-up mode, the symbol corresponded to the compass bearing to the airport. When the display was configured in a track-up mode, the symbol corresponded to the relative direction (from the current aircraft heading) to the airport. In the example shown in Figure 4, the aircraft is on a heading of 015 degrees. Airport 3F7 is at a bearing of 135 degrees. Airport H01 is at a bearing of 201 degrees. The storm front is approaching from the east. The pilot in this example should select the airport farther to the west, or H01.

The third method for presenting nearest airport information is shown in Figure 5. In this method, the nearest airports are shown directly on the map display, with an asterisk positioned next to the closest airport. In the example shown, the aircraft is on a heading of 165 degrees. The nearest airport, OK09, is at a bearing of 240 degrees and airport F61 is at a bearing of 145 degrees. Because the storm is approaching from the east, the pilot should select airport OK09 by pressing it on the touch screen.

For each of the trials, three performance measures were collected. One was the accuracy for selecting the airport located farther from the approaching storm front. A second was the response time required to make that decision. The third was the difference between the required aircraft heading and the actual aircraft heading at the end of the trial.

RESULTS

Decision Errors

All statistical analyses were performed using a significance threshold of 0.05. A 3 x 2 x 2 x 2 analysis of variance was performed on the number of decision errors committed by participants under each experimental condition. A decision error, for purposes of the experiment, was the selection of the airport closer to the approaching storm front, rather than the one farther away. The only factor to reach significance was the direction of travel, $F(1, 35) = 8.566$, $p = 0.006$, $MSE = 0.418$. Significantly more decision errors were committed when the aircraft was traveling in a southerly direction than when traveling in a northerly direction (40 vs. 21 errors respectively). No other main effects or interactions reached significance. However, several of the tests approached significance. These included the main effect due to map mode (north-up vs. track-up) $F(1, 35) = 3.007$, $p = 0.092$, $MSE = 0.260$; the map mode by display mode (text, graphics, enhanced-text) interaction, $F(2, 70) = 2.676$, $p = 0.076$, $MSE = 0.181$; the map mode by direction of travel interaction $F(1, 35) = 3.026$, $p = 0.091$, $MSE = 0.196$; the direction of travel by turbulence factor (turbulence on vs. turbulence off) interaction, $F(1, 35) = 3.718$, $p = 0.062$, $MSE = 0.140$; and the four-way interaction between all factors, $F(2, 70) = 3.034$, $p = 0.054$, $MSE = 0.130$.

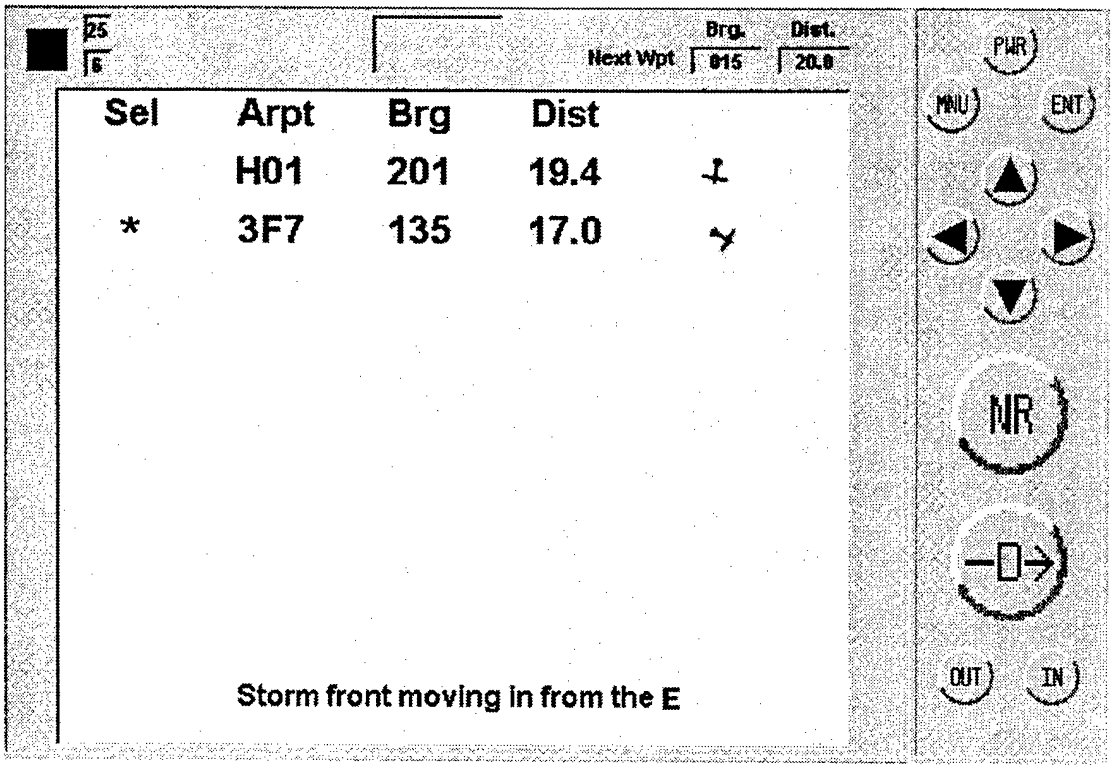

Figure 4: Enhanced-text method for presenting nearest airport information.

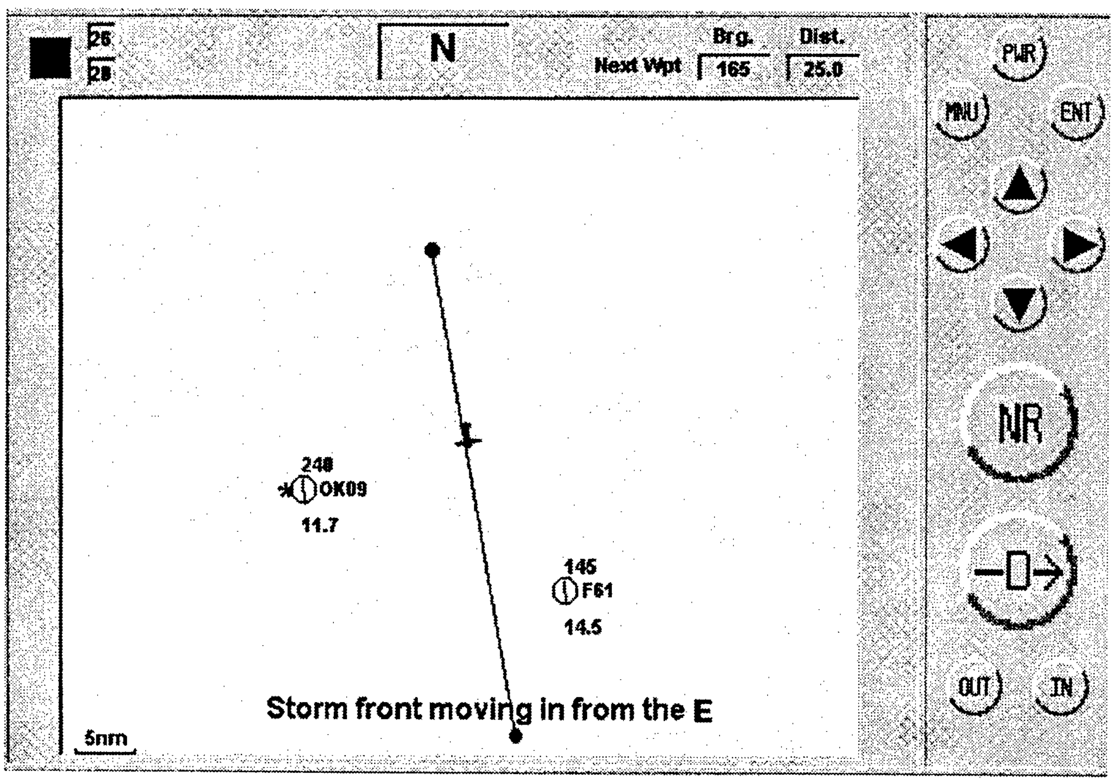

Figure 5: Map method for presenting nearest airport information (north-up mode).

Table 1: Decision errors breakdown

Map Mode	Direction of travel	Turbulence	Display Mode			
			E-Text	Graphics	Text	**Total**
N-up	North	Off	1	1	2	**4**
N-up	North	On	2	0	4	**6**
N-up	South	Off	3	0	4	**7**
N-up	South	On	3	1	2	**6**
		Total	**9**	**2**	**12**	**23**
T-up	North	Off	3	1	0	**4**
T-up	North	On	3	3	1	**7**
T-up	South	Off	7	6	3	**16**
T-up	South	On	3	3	5	**11**
		Total	**16**	**13**	**9**	**38**
					Grand Total	**61**

In all, 61 decision errors were committed. Table 1 provides a breakdown of the errors by each of the factors.

While none of the overall statistical analyses reflects the result, it is important to note that only two of the 61 errors were committed under the north-up map condition (see table above). More than six times as many errors (13) were committed in the comparable track-up map condition. A paired t-test was performed comparing the north-up and track-up map conditions only. Results showed that significantly more errors were committed under the track-up map condition, $t(35) = 3.179$, $p = 0.003$. The greatest number of errors (16) was committed under the track-up enhanced-text condition. In this condition, the airplane symbol pointed to the relative position of the airport from the current aircraft heading.

Decision Time

A 3 x 2 x 2 x 2 analysis of variance was performed on the time between presentation of nearest airport information until an airport was indicated by touching the touch-screen panel. Decision time was measured in milliseconds.

A significant effect was found for the map mode variable, $F(1, 35) = 28.47$, $p < 0.001$, MSE = 2.49E+08. Pilots were faster at deciding which airport was farther from the storm front under the north-up condition (4.27 seconds) than under the track-up condition (5.34 seconds). A significant effect was also found due to the type of display, $F(2, 70) = 25.061$, $p < 0.001$, MSE = 1.58E+08. Pilots were faster using the map display (3.94 seconds) than using either the text-only display (5.21 seconds) or the enhanced-text display (5.25 seconds). In addition to these main effects, a significant interaction was found between the map mode and display type, $F(2, 70) = 4.744$, $p = 0.012$, MSE = 26,657,085. No other main effect or interaction was significant; however, the main effect due to direction of travel of the aircraft approached significance, $F(1, 35) = 3.465$, $p = 0.071$, MSE = 15,412,044. The presence or absence of turbulence did not have any significant effect on decision time for any of the conditions.

Figure 6 shows the interaction between display type and map mode on response time. As can be seen from Figure 6, the significant interaction effect is primarily due to slower response times using the track-up map for the map and enhanced-text conditions, but not for the text-only condition. Post-hoc analyses using paired t-tests confirmed this finding, demonstrating a significant difference between the track-up and north-up modes using the map display, $t(35) = -6.648$, $p < 0.001$, SD = 1496.37, and between the track-up and north-up modes using the enhanced-text display, $t(35) = -2.954$, $p = 0.006$, SD = 2268.59, but not between the track-up and north-up modes using the text-only display, $t(35) = -1.651$, $p = 0.108$, SD = 1612.33. By far, the fastest decision times were for the north-up map display.

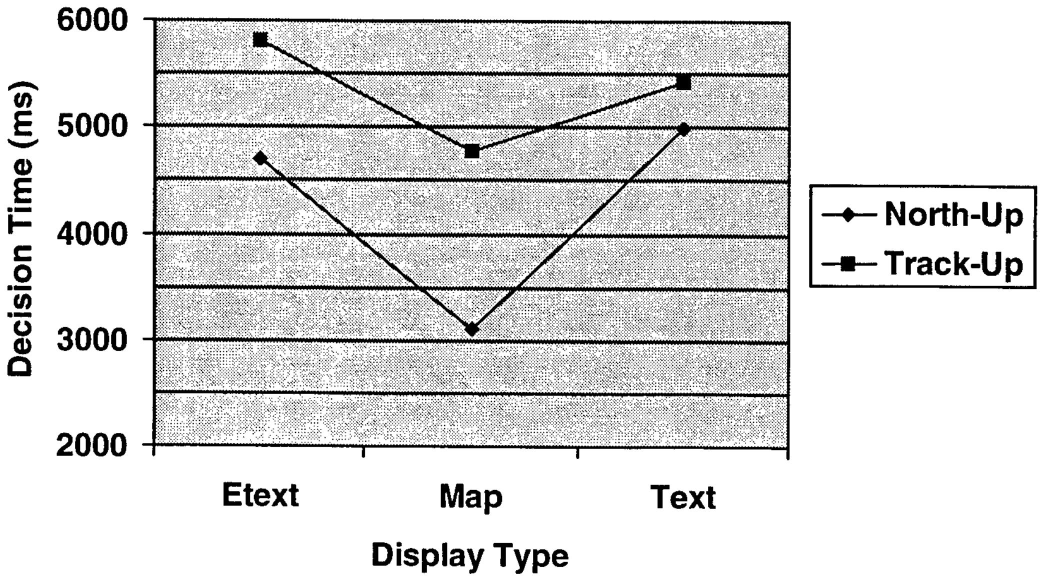

Figure 6: Decision time as a function of display type and map mode.

Flight Error

A 3 x 2 x 2 x 2 analysis of variance was performed on the difference between the intended and the actual aircraft heading at the end of each trial. During each trial, pilots were instructed to follow a path depicted on the GPS display. The path was always a straight-line course. The difference between this intended heading and the actual aircraft heading at the end of the trial is referred to as flight error.

The analysis revealed a significant effect due to map mode, $F(1, 35) = 4.361$, $p = 0.044$, $MSE = 142.594$. Pilots exhibited less flight error under the track-up condition than under the north-up condition. This finding replicates other work showing that track-up displays better support flight path guidance than north-up displays (e.g., Wickens, Liang, Prevett, & Olmos, 1996). The analysis also showed a significant effect due to turbulence being present or absent during the trial, $F(1, 35) = 18.637$, $p < 0.001$, $MSE = 943.76$. Not surprisingly, flight error was higher under turbulent conditions.

Post-test Questions

Following the completion of the experimental trials, pilots were asked two questions regarding which display type they preferred the most and whether or not they used the enhanced-text symbology during the decision task. Twenty-four of the thirty-six pilots (67%) stated that they preferred the north-up map display for performing the decision task. Four (11%) expressed a preference for the track-up map display. Six of the pilots (17%) stated they liked both map displays equally. One of the pilots preferred the north-up map and the enhanced-text display with the north-referenced airplane symbol equally. One pilot expressed equal preference for the track-up map and the enhanced-text display with the heading referenced airplane symbol.

Regarding actual use of the airplane symbol under the enhanced-text condition, 18 of the pilots (50%) stated that they did not use the symbol at all but instead, relied solely on the airport bearing information (making this condition equivalent to the text-only condition for those pilots). Of the pilots who used the enhanced-text symbology, six stated that they only used the symbol when it was north-referenced. One pilot stated that the symbol was used only when it was heading-referenced.

DISCUSSION

The results of this experiment, support the previous one (Williams, 1999), regarding the superiority of graphical over textual information display of nearest airport information. Pilots were significantly faster using the map display than using either the text-only display or the enhanced-text display. In addition, the fewest errors occurred under the graphical display condition. These results lend support to the notion that tasks that demand spatial/analog processes in

working memory will be best served by visual spatial displays (Wickens et al., 1983). Unlike the previous experiment, however, the inclusion of an orientation symbol in the text display did not eliminate the advantage shown by the graphical display. There are several reasons why this occurred. First, the task of selecting the airport farther from the approaching storm front did not require integrating the current aircraft heading with the bearing to the airport. Because no integration was required, the only advantage offered by the symbol was that it acted as a visual representation of the bearing to the airport under the north-up condition. Under the track-up condition, the symbol represented relative bearing to the airport, and for purposes of the decision task, offered no useful information to the pilot.

Second, only half of the pilots reported actually making use of the orientation symbol. Some pilots thought the symbol was confusing. This confusion could have been due to changing the symbol during the experiment between indicating the relative direction of the airport to indicating the absolute bearing to the airport. Other pilots stated that they preferred using the bearing information to the airport to make their judgments and did not even attempt to use the orientation symbol. Again, as with the previous experiment, more practice with the orientation symbol could alter these results.

Besides eliminating the advantage shown by the orientation symbol in the enhanced-text condition, the other result of changing the task from an ego-referenced judgment to a world-referenced judgment was to cause the north-up map mode to be more effective than the track-up map mode. Not only was it found that pilots responded significantly faster under the north-up condition than the track-up condition, but post hoc analysis revealed that far fewer errors were committed under the north-up map condition than under any of the other conditions.

Wickens, Liang, Prevett, & Olmos (1996) advocate the use of a track-up map as the default option of any computer-based map display to be used for navigation. However, this recommendation assumes that the primary navigational use of such a display would be to maintain lateral and vertical position along a course. Indeed, this experiment replicated the finding that a track-up display is more effective for lateral tracking than a north-up display. It is unlikely, though, that either a track-up or north-up map display would be used for real-time course guidance during flight. Instead, real-time course guidance would be provided either by a traditional course direction indicator or, in future systems, by some sort of highway-in-the-sky display (Reising, Liggett, Kustra, Snow, Hartsock & Barry, 1998).

The inclusion of only pilots in the present experiment demonstrated that experience using heading and bearing information does not eliminate the advantage that a graphical display of that information provides. Evidence that both the speed and accuracy of decisions can be affected by the choice of display formats was found in the current study. While some of the pilots expressed a preference for the text-based formats, most preferred the map-based display. In addition, while some preferred the track-up map display, most thought that the north-up display was the easier to use and most effective for the task that was performed.

The presence of turbulence did not have much effect on decision performance. This was evident in the lack of any significant interactions between the turbulence factor and any of the other factors. In contrast, though, there was a significant effect on flight error due to turbulence. Rather than expending additional resources on controlling the aircraft under turbulent conditions, pilots may have focused their attention on interacting with the display. If true, this outcome is consistent with previous research demonstrating that pilots tend to ignore flying the aircraft while interacting with the GPS display (Williams, 1999; Wreggit & Marsh, 1998).

Most, if not all, current manufacturers of GPS units have elected to present nearest airport information in a text-only format. Sometimes this information is presented in a tabular form that allows comparison among several alternatives, but other times each airport is presented one at a time, starting with the closest airport. The most likely reason that the information is presented only textually is a matter of precedence. The design of GPS units was based on the design of earlier systems used for area navigation (i.e., Loran). Because these earlier systems were designed at a time when display capabilities were more restricted, all information was presented as text-only. As new display capabilities arrived, added functionality took advantage of these capabilities; however,

the format for the nearest airport function was already established. This suggests that the next generation of navigational displays will continue propagating design decisions made for older displays and that only new functionality will take advantage of the new display capabilities. Integrated displays will make it possible to have weather, traffic, and terrain information available simultaneously to the pilot. This integration should allow presentation of nearest airport information in a graphical format that will include weather, terrain, and traffic. Such a presentation format would improve the decision-making process and allow more useful information to be included in the decision, but only if designers of new displays are willing to abandon previous display design decisions.

For now, the following recommendations can be made regarding the display of nearest-airport information:

- Nearest-airport information should be presented in a format that best supports the types of decisions to be made with this information. Based on the current study and previous research (Williams, 1999), the best format is a graphical format in which relative and absolute direction and distance can be determined from among a small set of alternatives.
- In the absence of integrated graphical weather, terrain, and traffic displays, the use of a north-up map is superior to a track-up map for orienting to world-referenced obstacles.
- Use of a track-up presentation might be acceptable for orienting to world-referenced obstacles if an intuitive and easily interpreted way to indicate cardinal directions were present within the display.
- Use of a track-up map is superior when orienting to self-referenced obstacles. An example of this would be orienting toward the runway during conduct of an instrument approach.
- The use of graphical symbols within a text display can improve the usefulness and effectiveness of the display but a certain amount of training will be needed with the display before it can be used efficiently.

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